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PATENT

SCLERAL EXPANSION DEVICE HAVING DUCK BILL

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CROSS REFERENCE TO RELATED APPLICATIONS

5 This application claims priority under 35 U.S.C. § 119(e)(1) to United States Provisional Patent Application No. 60/206,134 filed May 22, 2000, and is a continuation-in-part of: (1) United States Patent Application Serial No. 09/061,168, entitled "SCLERAL PROSTHESIS FOR TREATMENT OF PRESBYOPIA AND OTHER EYE DISORDERS" and
10 filed on April 16, 1998, which application is a continuation-in-part of United States Patent Application Serial No. 08/946,975 entitled "SCLERAL PROSTHESIS FOR TREATMENT OF PRESBYOPIA AND OTHER EYE DISORDERS" and filed October 8, 1997, now United States Patent No. 6,007,578 issued December 28, 1999; (2) United States Patent
15 Application Serial No. 09/472,535 entitled "SCLERAL PROSTHESIS FOR TREATMENT OF PRESBYOPIA AND OTHER EYE DISORDERS" and filed December 27, 1999, which application is a continuation of United States Patent Application Serial No. 08/946,975; (3) United States Patent Application Serial No. 09/589,626 entitled "IMPROVED SCLERAL
20 PROSTHESIS FOR TREATMENT OF PRESBYOPIA AND OTHER EYE DISORDERS" and filed June 7, 2000, which application is a continuation-in-part of United States Patent Applications Serial Nos. 08/946,975, 09/061,168 and 09/472,535. All of the above-identified documents,

and the inventions disclosed therein, are incorporated herein by reference for all purposes as if fully set forth herein.

TECHNICAL FIELD OF THE INVENTION

5 This invention relates to methods of treating presbyopia, hyperopia, primary open angle glaucoma and ocular hypertension and more particularly to methods of treating these diseases by increasing the effective working distance of the ciliary muscle. 10 The invention also relates to increasing the amplitude of accommodation of the eye by increasing the effective working range of the ciliary muscle.

BACKGROUND OF THE INVENTION

15 In order for the human eye to have clear vision of objects at different distances, the effective focal length of the eye must be adjusted to focus the image of the object as sharply as possible on the retina. Changing the effective focal length is known as accommodation, and is accomplished in the eye by varying the shape 20 of the crystalline lens. Generally the curvature of the lens in an unaccommodated emmetropic eye allows distant objects to be sharply imaged on the retina, while near objects are not focused sharply on

the retina in the unaccommodated eye because the image lie behind the retinal surface. In order to perceive a near object clearly, the curvature of the crystalline lens is increased, thereby increasing the refractive power of the lens and causing the image
5 of the near object to fall on the retina.

The change in shape of the crystalline lens is accomplished by the action of certain muscles and structures within the eyeball or globe of the eye. As described in greater detail in, for example, U.S. Patent No. 6,146,366, the lens has the shape of a classical
10 biconvex optical lens--that is, generally circular with two convex refracting surfaces--and is located in the forward part of the eye immediately behind the pupil and generally on the optical axis of the eye (i.e., a straight line drawn from the center of the cornea to the macula in the retina at the posterior portion of the globe).
15 In the unaccommodated human eye the curvature of the posterior surface of the lens (the surface adjacent to the vitreous body) is somewhat greater than that of the anterior surface.

The lens is closely surrounded by a membranous capsule that serves as an intermediate structure in the support and actuation of
20 the lens. The lens and the capsule are suspended on the optical axis behind the pupil by a circular assembly of many radially directed elastic fibers, the zonules, which are attached at inner ends to the lens capsule and at outer ends to the ciliary muscle,

a muscular ring of tissue located just within the outer supporting structure of the eye, the sclera. The ciliary muscle is relaxed in the unaccommodated eye and therefore assumes a maximum diameter. According to the classical theory of accommodation, originating with Helmholtz, the relatively large diameter of the ciliary muscle in this condition causes a tension on the zonules, which in turn pull radially outward on the lens capsule and cause the equatorial diameter of the lens to increase slightly while decreasing the anterior-posterior dimension (thickness) of the lens at the optical axis. Thus, the tension on the lens capsule causes the lens to assume a flattened state wherein the curvature of the anterior surface, and to some extent the posterior surface, is less than the curvature which would exist in the absence of the tension. In this state the refractive power of the lens is relatively low and the eye is focused for clear vision for distant objects.

To focus the eye on a near object, the ciliary muscles contract. According to the classical theory, this contraction causes the ciliary muscle to move forward and inward, thereby relaxing the outward pull of the zonules on the equator of the lens capsule. Such reduced zonular tension allows the elastic capsule of the lens to contract, causing an increase in the antero-posterior diameter (thickness) of the lens (i.e., the lens becomes more spherical) and resulting in an increase in the optical power

of the lens. Because of topographical differences in the thickness of the lens capsule, the central anterior radius of curvature decreases more than the central posterior radius of curvature. This constitutes the accommodated condition of the eye, wherein the image of near objects falls sharply on the retina.

Presbyopia is the universal decrease in the amplitude of accommodation that is typically observed in individuals over 40 years of age. In the person having normal vision (i.e., having emmetropic eyes) the ability to focus on near objects is gradually lost, and the individual comes to need glasses for tasks requiring near vision, such as reading.

According to the conventional view the amplitude of accommodation of the aging eye is decreased because of the loss of elasticity of the lens capsule and/or sclerosis of the lens with age. Consequently, even though the radial tension on the zonules is relaxed by contraction of the ciliary muscles, the lens does not assume a greater curvature. According to the conventional view, treatment to restore the accommodative power to the presbyopic eye is not possible. The loss of elasticity of the lens and capsule is seen as irreversible, and the only solution to the problems presented by presbyopia is to use corrective lenses for close work, or bifocal lenses, if corrective lenses are also required for distant vision.

In contrast to the conventional (Helmholtz) theory, the Schachar theory of accommodation--on which the related patent applications identified above are based--postulates that outward equatorial displacement of the crystalline lens produces a central steepening (and peripheral flattening) of the lens surface. The equatorial displacement results from increased tension on the equatorial zonules which is produced, in turn, by contraction of the anterior radial muscle fibers of the ciliary muscle. Since active force is involved in accommodation, the amount of force which may be applied to the lens equator is dependent on how much the ciliary muscle is stretched. Since the crystalline lens is of ectodermal origin and continues to grow throughout the life of an individual while the dimensions of the scleral shell do not change significantly after 13 years of age (with certain exceptions), the distance between the ciliary muscle and the equator of the lens decreases throughout the life of an individual. Therefore, the effective force which the ciliary muscle may apply to the lens equator is reduced with age, such that the decrease in the amplitude of accommodation resulting in presbyopia is a consequence of normal lens growth.

Such continued lens growth decreases the working distance of the zonules and ciliary muscle, decreasing the range of accommodation which may be achieved by contracting the ciliary

muscle to a point where focusing near objects on the retina is no longer possible. Under this view, presbyopia may be suitably treated by increasing the effective working distance of the ciliary muscle, such as by increasing the distance between the ciliary muscle and the lens equator, preferably by increasing the diameter of the sclera (i.e., scleral expansion) in the region of the ciliary body.

Prostheses have been disclosed in the related applications identified above for treating presbyopia by implantation within a number of elongated pockets formed in the sclera of the eye transverse to a meridian of the eye, expanding the sclera and restoring the effective working distance of the ciliary muscle. However, as disclosed in serial no. 09/589,626 ("the '626 application"), such prostheses may exhibit a tendency to slide back and forth within the scleral pocket or to turn or topple over within the scleral pocket, reducing the effectiveness of the prostheses in treating presbyopia in either case. In particular, prosthesis embodiments which have a circumferential shape including a curved bottom surface may have limited surface contact between the bottom surface and the inner wall of the surgically formed scleral pocket, generally in the area of the first and second ends of the prosthesis, and therefore suffer stability problems due at least in part, to the disproportionate surface contact of the top

surface of the prosthesis relative to the bottom surface.

There is, therefore, a need as disclosed in the '626 application to improve the stability of a prosthesis inserted within a scleral pocket for treatment of presbyopia and other eye disorders.

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SUMMARY OF THE INVENTION

A prosthesis for scleral expansion includes a central body portion and at least one end portion having a width greater than the width of the central body portion. The end portion therefore inhibits rotation of the prosthesis about a long axis when the prosthesis is implanted within a scleral pocket or tunnel. The other end of the central body portion may have a blunted end portion including grooves for receiving a edge or lip of an incision forming the scleral tunnel to inhibit the prosthesis from sliding within the scleral tunnel. Curvature of the bottom surface of the central body portion may be greater than the curvature of the innermost surface of the scleral tunnel so that contact between the scleral and the bottom surface of the prosthesis is primarily with the end portions.

The foregoing has outlined rather broadly the features and technical advantages of the present invention so that those skilled in the art may better understand the detailed description of the invention that follows. Additional features and advantages of the invention will be described hereinafter that form the subject of the claims of the invention. Those skilled in the art should appreciate that they may readily use the conception and the specific embodiment disclosed as a basis for modifying or designing

other structures for carrying out the same purposes of the present invention. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the invention in its broadest form.

BRIEF DESCRIPTION OF THE DRAWINGS

An advantageous embodiment of the present invention may be understood with reference to the following descriptions taken in conjunction with the accompanying drawings, wherein like numbers designate like objects, in which:

FIGURES 1A and 1B are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to one embodiment of the present invention;

FIGURES 1C and 1D are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to another embodiment of the present invention;

FIGURES 1E and 1F are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to another embodiment of the present invention;

FIGURE 1G is a top plan view of a prosthesis for increasing the effective working distance of the ciliary muscle by

implantation into surgically formed scleral tunnels according to another embodiment of the present invention;

FIGURE 1H is a top plan view of a prosthesis for increasing the effective working distance of the ciliary muscle by
5 implantation into surgically formed scleral tunnels according to another embodiment of the present invention;

FIGURE 1I is a side elevation view of a prosthesis for increasing the effective working distance of the ciliary muscle by
10 implantation into surgically formed scleral tunnels according to another embodiment of the present invention;

FIGURE 1J is a side elevation view of a prosthesis for increasing the effective working distance of the ciliary muscle by
15 implantation into surgically formed scleral tunnels according to another embodiment of the present invention;

FIGURES 2A and 2B are longitudinal cross-sectional views of the central body portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention;

FIGURES 3A through 3E are transverse cross-sectional views of the central body portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to
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various alternative embodiments of the present invention;

FIGURES 4A through 4D are transverse cross-sectional views of duck bill end portions of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention;

FIGURES 5A and 5B are longitudinal cross-sections of duck bill end portions of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention; and

FIGURE 6 is a longitudinal cross-section of a blunted end portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

According to present invention, presbyopia and certain other eye disorders (e.g., hyperopia, primary open angle glaucoma, ocular hypertension, etc.) may suitably be treated by increasing the effective working distance of the ciliary muscle. Such increase may be achieved by increasing the distance between the ciliary muscle and the lens equator, preferably by increasing the diameter of the sclera (i.e., scleral expansion) in the region of the ciliary body. According to one embodiment of the present invention, the effective working distance of the ciliary muscle may suitably be increased by implanting, within pockets surgically formed in the sclera of the eye, a plurality of prostheses designed to place an outward traction on the sclera in the region of the ciliary body.

FIGURES 1A and 1B are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to one embodiment of the present invention. Prosthesis 100 includes a central body portion 101 connecting end portions 102 and 103. As with the prostheses described in the related applications described above, prosthesis 100 is intended to be inserted within a surgically

formed pocket or tunnel within the sclera, elevating a portion of the sclera to increase the effective working distance of the ciliary muscle.

The planform of exemplary prosthesis 100 of FIGURES 1A-1B includes "duck bill" end portions 102 and 103 which are wider and flatter (and, in the exemplary embodiment, thinner) than the intermediate central body portion 101. These "duck bill" end portions promote stability when the prosthesis 100 is within the scleral tunnel, inhibiting the prosthesis 100 from turning or toppling over (i.e., rotating about a long axis of the prosthesis 100) within the scleral tunnel.

When prosthesis 100 is inserted within a scleral tunnel, essentially all of central body portion 101 is preferably contained within the tunnel, while essentially all of end portions 102 and 103 are preferably outside the scleral tunnel (i.e., the scleral tunnel has a length approximately equal to the length of central body portion 101 of prosthesis 100). In such instances, central body portion 101 is within the sclera or under the scleral layer, while end portions 102 and 103 are on the sclera, a bottom surface of end portions 102 and 103 in contact with an outer surface of the sclera. Alternatively, however, one or more portions of central body portions 101 proximate to end portions 102 and/or 103 may be outside the scleral tunnel, or one or more portions of end portions

102 and/or 103 may be within the tunnel (i.e., the scleral tunnel has a length which is either greater than or less than the length of central body portion 101 of prosthesis 100).

FIGURES 1C and 1D are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to another embodiment of the present invention. In the embodiment of FIGURES 1C-1D, one duck bill end portion 102 projecting from the central body portion 101 of the prosthesis 110 is wider and/or thicker than the other duck bill end portion 104. During insertion of the prosthesis 110 within a scleral tunnel, narrower and/or thinner end portion 104 is intended to be passed through both incisions within the sclera which form the ends of the scleral tunnel. The benefits of having one duck billed end portion 104 which is narrower and/or thinner than the other is addressed in further detail below.

FIGURES 1E and 1F are a top plan view and a side elevation view, respectively, of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to another embodiment of the present invention. Prosthesis 120 in the embodiment of FIGURES 1E-1F includes only duck billed end portion 102 projecting from the central body portion 101. The other end of

the central body portion may have no end portion, or, as shown in the example of FIGURES 1E-1F, may have an end portion 105 which is not wider than central body portion 101. In the example shown, blunted end portion 105 is not as long as duck bill end portion 102. However, blunted end portion 105 is substantially thicker than duck bill end portion 102, tapering from the thickness of central body portion 101 to an end thickness to a lesser degree than does duck bill end portion 102.

Prosthesis 120 may be implanted in a scleral pocket (i.e., a passage either into and along or through or under the scleral layer which has only one opening) rather than a scleral tunnel (a passage either into, along and out of the scleral layer or through, under and back through the scleral layer, with two openings, one at either end). Preferably, however, prosthesis 120 is implanted in a scleral tunnel with substantially all of central body portion 101 within the scleral tunnel (either within or under the scleral layer) while duck bill end portion 102 and blunted end portion 105 are both substantially outside the scleral tunnel resting on the outer surface of the sclera. Advantages of having blunted end portion 105 outside the scleral tunnel are described in further detail below.

Dashed line 190 within duck bill end portion 102 illustrates that the end portions which are wider than the central body

portions of a prosthesis need not increase in width uniformly in both directions (on both sides), but may instead increase in width only on one side with the other side retaining planar alignment with the side of the central body portion.

5 FIGURE 1G is a top plan view of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to another embodiment of the present invention. The planform of the central body portion 111 for prosthesis 130 in FIGURE 1G is
10 circumferential--that is, shaped to follow a portion of a circle around the lens of the eye. While the sides surfaces 160 and 161 of central body portion 101 depicted in FIGURES 1A, 1C and 1E are straight along a long axis of the respective prosthesis 100, 110 or 120, the side surfaces 162 and 163 of prosthesis 130 are both
15 curved along the long axis of prosthesis 130. Side surfaces 162 and 163 are both curved in the same direction (with side surface 162 being convex and side surface 163 being concave) and preferably having a common focal point for the radius of curvature. However, the two sides 162 and 163 may have differing degrees of curvature
20 (i.e., each having a different focal point for the respective radius of curvature). The prosthesis 130 of FIGURE 1G is intended to be implanted within a scleral tunnel with side surface 162 further from the lens than side surface 163. Use of an end portion

which widens only on one side (e.g., the outer edge) may be useful in this embodiment and other embodiments where rotation of the implanted prosthesis is much more likely in one direction than in the opposite direction.

5 FIGURE 1H is a top plan view of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to another embodiment of the present invention. While the sides surfaces 160 and 161 of central body portion 101 depicted in FIGURES 1A, 1C and 1E are straight along a long axis of the
10 respective prosthesis 100, 110 or 120 and the side surfaces 162 and 163 of the central body portion 111 depicted in FIGURE 1G are both curved in the same direction, side surfaces 164 and 165 of the central body portion 121 for prosthesis 140 are curved, along the long axis of prosthesis 140, in opposite directions. In the
15 example shown, both side surfaces 164 and 165 are concave, and have identical curvatures (i.e., the same radius of curvature, although with different focal points). However, the side surfaces may alternatively both be convex and/or may have different curvatures.

20 In the example shown, end portions 102 and 103 are wider than the wide point(s) of central body portion 121 (i.e., the ends of the central body portion 121 for the embodiment depicted in FIGURE 1H). In accordance with the present invention, however, end

portions 102 and 103 need only be wider than some portion of central body portion 121 (i.e., should be wider than the narrowest portion of central body portion 121) to improve stability of the prosthesis 140 within the scleral tunnel.

5 It should be noted that while prostheses 130 and 140 are depicted in FIGURES 1G and 1H as having equally sized duck bill end portions 102 and 103 as described above with respect to prosthesis 100 depicted in FIGURE 1A and 1B, either prosthesis 130 or 140 may instead include a duck bill end portion at one end of central body portion 111 or 121 which is smaller and/or thinner than the duck bill end portion at the opposite end, in the manner of prosthesis 110 depicted in FIGURES 1C and 1D (end portions 102 and 104). Likewise, either prosthesis 130 or 140 may alternatively include a duck bill end portion at one end of central body portion 111 or 121 and a blunted end portion at the opposite end, in the manner of prosthesis 120 depicted in FIGURES 1E and 1F (end portions 102 and 105).

FIGURE 1I is a side elevation view of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to another embodiment of the present invention. While the bottom surface 170 of the central body portion 101 depicted in FIGURES 1B, 1D and 1F is curved (concave) along a long axis of the prosthesis

100, 110 or 120, prosthesis 150 includes a central body portion 131 having a bottom surface 171 which is straight along the long axis of prosthesis 150 (but which may be curved in other directions, as described in further detail below). Alternatively, the bottom surface of the central body portion may be convex along the long axis of the prosthesis.

Central body portions 111 and 121 depicted in FIGURES 1G and 1H may have a bottom surface which is concave along the long axis of the respective prosthesis 130 or 140, similar to central body portion 101 in FIGURES 1B, 1D and 1F, flat along the long axis in the manner depicted for central body portion 131 depicted in FIGURE 1I, or convex along the long axis. Moreover, while prostheses 150 is depicted in FIGURE 1I as having equally sized duck bill end portions 102 and 103 as described above with respect to prosthesis 100 depicted in FIGURE 1A and 1B, prosthesis 150 may instead include either: (1) a first duck bill end portion at one end of central body portion 131 which is smaller and/or thinner than a second duck bill end portion at the opposite end, in the manner of prosthesis 110 depicted in FIGURES 1C and 1D (end portions 102 and 104); or (2) a duck bill end portion at one end of central body portion 131 and a blunted end portion at the opposite end, in the manner of prosthesis 120 depicted in FIGURES 1E and 1F (end portions 102 and 109).

FIGURE 1J is a side elevation view of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral tunnels according to another embodiment of the present invention. While the end portions 102-105 are depicted in FIGURES 1B, 1D, 1F and 1I as being substantially aligned with the respective central body portion 101 or 131, end portions 106 and 107 in prosthesis 160 are angled with respect to central body portion 101. That is, the planes 180 and 181 with which end portions 106 and 107 are aligned (taken with respect to the bottom surfaces 190 and 191 of end portions 106 and 107) are angled with respect to, and intersect, the plane 182 with which central body portion 101 or 131 is aligned (again, taken with respect to the bottom surface 170 or 171 of central body portion 101 or 131). By contrast, the planes with which end portions 102-105 are aligned are at least parallel with the planes to which central body portions 101 and 131 are aligned; end portions 102-105 and central body portions 101 and 131 may, in fact, be aligned with the same plane.

Such angling of end portions 106 and 107 with respect to the central body portion 101 is preferably sufficient to allow the bottom surfaces 190 and 191 to be substantially tangential to the surface of the sclera on which such end portions 106 and 107 rest when prosthesis 160 is implanted within a scleral tunnel. End

portions 102, 103 and/or 104 may also be angled with respect to the corresponding central body portions 101, 111, 121 or 131 in the prostheses 120, 130, 140 and 150 depicted in FIGURES 1C and 1F through 1I. Moreover, only one end portion (e.g., end portion 102) may be angled with respect to a central body portion, while the opposite end portion (e.g., duck bill end portion 104 or blunted end portion 105) may be substantially aligned with the corresponding central body portion.

Those skilled in the art will understand that any of the various alternative embodiments described or suggested above which includes either no end portion or a blunted end portion at one end of the respective prosthesis may be implanted within a scleral pocket rather than a scleral tunnel.

FIGURES 2A and 2B are longitudinal cross-sectional views of the central body portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention. FIGURES 2A and 2B depict a cross-section taken along section lines A-A, along a long axis of the prosthesis, with the end portions broken away. The central body portion cross-sections 200 and 201 depicted in FIGURES 2A and 2B may correspond to any of central body portions 101, 111 or 121 depicted in FIGURES 1A-1H and 1J.

As shown in both central body portion cross-sections 200 and 201, the top surface 172 of the central body portion has a convex curvature along the long axis of the respective prosthesis (e.g., prosthesis 100, 110, 120, 130, 140 or 160). Alternatively, the top surface of the central body portion may be straight or have a concave curvature.

As illustrated in FIGURES 1B, 1D, 1F and 1J, bottom surface 170 has a concave curvature along a long axis of the respective prosthesis. The bottom surface 170a may have a curvature which is approximately equal to a curvature of the innermost surface 202 of the scleral tunnel into which the prosthesis is to be implanted (i.e., the curvature of the remaining scleral layer underlying the scleral tunnel for an intra-scleral tunnel or, where the scleral tunnel is formed between the sclera and the underlying tissue, of the tissue underlying the scleral layer).

As illustrated in FIGURE 2B and described in the '626 application, however, the bottom surface 170b may have a curvature which is greater than the curvature of the innermost surface 202 of the scleral tunnel (i.e., a smaller radius of curvature), such that the prosthesis rests primary on the end portions and/or end regions of the central body portion when implanted, with the bottom surface 170b in a middle area of the central body portion spaced apart from the underlying innermost surface 202 of the scleral tunnel.

FIGURES 3A through 3E are transverse cross-sectional views of the central body portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention. FIGURES 3A through 3E depict a cross-section taken along section lines B-B, transverse to a long axis of the prosthesis. The central body portion cross-sections depicted in FIGURES 3A through 3E may correspond to any of central body portions 101, 111, 121 or 131 depicted in FIGURES 1A-1J.

In the embodiment depicted in FIGURE 3A, the bottom and top surfaces 170a and 172a are both straight in a direction transverse to the long axis of the prosthesis, as are side surfaces 160a and 161a. In the embodiment of FIGURE 3B, however, while the top surface 172b and side surfaces 160b and 161b are all straight in directions transverse to the long axis of the prosthesis, the bottom surface 170b is curved in a direction transverse to the long axis of the prosthesis. The curvature of the example shown is approximately equal to the curvature of the innermost surface 202 of the scleral tunnel into which the prosthesis is to be implanted. The bottom surface 170c in the embodiment of FIGURE 3C is similarly curved in a direction transverse to the long axis of the prosthesis, but with a curvature greater than the curvature of the

innermost surface 202 of the scleral tunnel. Top surface 172c and sides surfaces 160c and 161c are straight.

In the embodiment of FIGURE 3D, the side surfaces 160d and 161d, while straight, are angled with respect to each other rather than being substantially parallel. Top surface 172d has a convex curvature in a direction transverse to the long axis of the prosthesis, and bottom surface 170d has a concave curvature.

While the side surfaces 160d and 161d are uniformly or equally sloped in the embodiment of FIGURE 3D, the side surfaces may be unequally sloped as shown in FIGURE 3E to form an oblique profile. Side surfaces 160e and 161e are straight, and sloped to different degrees, while top surface 172e has a convex curvature and bottom surface 170e has a concave curvature.

Either or both of the side surfaces may alternatively be curved, either convexly or concavely, in a direction transverse to the long axis of the prosthesis, regardless of whether the side surfaces are substantially parallel to each other or angled with respect to each other. Moreover, the top surface may have a concave curvature, or the bottom surface may have a convex curvature.

While reference is made to side surfaces 160 and 161 and top and bottom surfaces 172 and 170 with respect to FIGURES 3A-3E, the profiles and/or curvatures illustrated are equally applicable to

sides surfaces 162-165 or bottom surface 171. For example, while bottom surface 171 depicted in FIGURE 1I is straight along a long axis of the prosthesis, the same surface may be curved in a direction transverse to the long axis in the manner illustrated in FIGURES 3B-3C.

FIGURES 4A through 4D are transverse cross-sectional views of duck bill end portions of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention. FIGURES 4A through 4D depict a cross-section taken along section lines C-C, transverse to a long axis of the prosthesis, with the remainder of the prosthesis broken away. The end portion cross-sections depicted in FIGURES 4A through 4D may correspond to any of end portions 102, 103, 104, 106 or 107 depicted in FIGURES 1A-1J.

In the embodiment of FIGURE 4A, the top and bottom surfaces 400a and 401a of the end portion are straight in a direction transverse to the long axis of the prosthesis. Comparison of FIGURE 3A with FIGURE 4A shows that the prosthesis (which may be prosthesis 100, 110, 130, 140, 150 or 160) has a cross-section within the end portions which is wider and thinner than the cross-section of the central body portion. However, the cross-sectional circumference and/or area of the end portions should preferably not

be significantly greater than the cross-sectional circumference and/or area of the central body portion. In this manner, the end portion may pass through an incision forming an opening to a scleral tunnel intended to accommodate the central body portion without tearing. The size of the surgical incision required to form a scleral tunnel which will admit the central body portion of the prosthesis without tearing (i.e., an incision having a length which is at least twice the circumference of the cross-section of the central body portion) will also permit passage of the end portion therethrough without tearing.

Most preferably, the cross-sectional circumference and/or area of the end portion intended to pass through the scleral tunnel should be equal to or less than the cross-sectional circumference and/or area of the corresponding central body portion. For this reason, an embodiment such as that illustrated in FIGURE 1C-1D, in which one duck bill end portion is narrower and/or thinner than the other, may be beneficially employed. Dashed outline 402 illustrates a relative proportion for the differently sized duck bill end portions.

FIGURE 4B illustrates an embodiment including a top surface 400b which is straight but a bottom surface 401b which is curved along a direction transverse to the long axis of the prosthesis. The curvature of the bottom surface 401b in the example of FIGURE

4B is approximately equal to the curvature of the scleral surface 403 upon which the respective end portion is intended to rest following implantation of the prosthesis.

FIGURE 4C similarly illustrates an embodiment including a top surface 400c which is straight but a bottom surface 401c which is curved along a direction transverse to the long axis of the prosthesis. However, the curvature of the bottom surface 401c in FIGURE 4C is greater than the curvature of the sclera surface 403 upon which the respective end portion is intended to rest following implantation of the prosthesis. In this manner, the force of contact between the duck bill end portions and the underlying sclera occurs near the edge of the respective end portion, maximizing the effect of the end portion in preventing rotation of the implanted prosthesis.

FIGURE 4D illustrates an embodiment in which both the top surface 400d and the bottom surface 401d which is curved along a direction transverse to the long axis of the prosthesis.

FIGURES 5A and 5B are longitudinal cross-sectional views of duck bill end portions of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to various alternative embodiments of the present invention. FIGURES 5A and 5D depict a cross-section of an end portion taken along section

lines A-A with the remainder of the prosthesis broken away. The end portion cross-sections depicted in FIGURES 5A and 5B may correspond to any of end portions 102, 103, 104, 106 or 107 depicted in FIGURES 1A-1J.

5 FIGURE 5A depicts an embodiment in which the top surface 500a is straight but the bottom surface 501a of a duck bill end portion is curved along the long axis of the prosthesis, at least in a central area of the end portion (i.e., the cross-section may be straight near an edge of the end portion). The curvature of the
10 bottom surface 501a in the example of FIGURE 5A is approximately equal to the curvature of the scleral surface 403 upon which the respective end portion is intended to rest following implantation of the prosthesis.

15 FIGURE 5B depicts an embodiment in which both the top surface 500b and the bottom surface 501a of a duck bill end portion are curved along the long axis of the prosthesis, at least in a central area of the end portion.

20 FIGURE 6 is a longitudinal cross-section of a blunted end portion of a prosthesis for increasing the effective working distance of the ciliary muscle by implantation into surgically formed scleral pockets or tunnels according to one embodiment of the present invention. Blunted end portion 105 includes one or more grooves 600 or 601, in the bottom surface, the top surface or

both. Although not shown in FIGURE 1F, grooves 600 and 601, if present, preferably extend across an entire width of the end portion 105. Grooves may be uniform, similar to groove 601, or oblique, similar to groove 600, and are intended to "catch" the lip of a scleral incision through which the prosthesis is inserted to inhibit sliding of the prosthesis within the scleral tunnel.

The dimensions of the central body portion of the prosthesis of the present invention are similar to the overall prosthesis dimension (including lengths, widths, thickness, and radii of curvature/heights for various curved surfaces) given in the related applications identified above. The prosthesis of the present invention may be fabricated of the same materials, and in the same manner, as those described in the related applications. Additionally, in treatment of eye disorders utilizing the prosthesis of the present invention, a number of prostheses are implanted in a single eye in the same manner as described in the related applications.

The present invention has been described in detail. Those skilled in the art will understand that various changes, substitutions and alterations may be made herein without departing from the spirit and scope of the invention in its broadest form.